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Comparison between meteorological data from the New Zealand National Institute of Water and Atmospheric Research (NIWA) and data from independent meteorological stations

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Abstract

Background: Hybrid eco-physiological/mensurational models of forest production generally require monthly meteorological estimates at local points in the landscape as inputs. Where to obtain these estimates and how best to localise them are important questions for modellers. Data collected from nine independent meteorological stations were compared with estimates from the nearest grid points of the Virtual Climate Station Network created by the New Zealand National Institute of Water and Atmospheric Research (NIWA) and also to estimates from NIWA's nearest actual meteorological stations.

Findings: Localisation of temperature estimates was attempted through simple adiabatic adjustments of NIWA's data and also adjustments that use elevation above sea level, latitude and distance from the sea. The latter adjustment was found to be slightly better than simple adiabatic adjustment. Results showed that useable local estimates can be obtained from absolute global solar radiation and adjusted mean daily maximum and minimum temperatures although there were small amounts of bias. Rainfall and relative humidity were not as well estimated for local points as the other variables and these poorer estimates may constrain our ability to model forest productivity in drier regions of New Zealand.

Conclusions: Monthly mean global radiation, and suitably adjusted estimates of mean daily maximum and minimum temperature from the Virtual Climate Station Network were found to estimate these properties for points in the landscape with reasonable precision and small bias. Rainfall, however, was imprecisely estimated.

Keywords: Growth and yield, Hybrid modelling, Climate, Weather

Findings

Introduction

Eco-physiological modelling of forest production relies heavily on local meteorological data in order to calculate constraints of photosynthesis, and we need to clearly identify the precision and bias associated with sources of such data.

A typical eco-physiological or "hybrid" model of forest growth and yield exploits a linear relationship between intercepted radiation and forest net primary productivity (Monteith 1972, 1977). The slope of the relationship has been labelled "quantum efficiency," and it is influenced by air temperature, soil moisture status, vapour pressure deficit (VPD), soil nutrition and plant physiological age. The idea of reducing maximum achievable quantum efficiency with modifiers that represent these influences is the basis of the 3-PG model (Landsberg and Waring 1997). Modifiers vary between 0 and 1 and are generally calculated using models of sub-processes such as water balance models or predictions of the impact of VPD on stomatal conductance. In order to work effectively, sub-models

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require accurate inputs of meteorological data, particularly rainfall, daily maximum temperature, daily minimum temperature, VPD and daily global or (if available) photosynthetically active radiation.

Eco-physiological models have been made to operate at a variety of temporal scales (McMurtrie and Wolf 1983a, 1983b; McMurtrie and Landsberg 1992; McMurtrie et al. 1990), but hybrid models of forest production used for management purposes usually employ a monthly time step (Mason et al. 2011; Mason et al. 2007).

The objectives of the study described here were to:

1) Determine the precision and bias of available estimates of meteorological data for particular points in the New Zealand landscape by comparing the estimates with measurements at independent meteorological stations
2) Identify any adjustments that might be made using other information, such as elevation, that might improve estimates for those points

Two alternative estimates of weather data were available:

1) Data from the nearest available NIWA meteorological station were adjusted for differences in elevation, latitude and distance from the sea. Such adjustments were made using simple adiabatic adjustments and using equations reported by Norton (1985).
2) Estimates from the National Institute of Water and Atmospheric Research's (NIWA) "Virtual Climate Station Network" (VCSN) (Cichota et al. 2008; Tait et al. 2006), a grid of points at approximately 5 km spacing across New Zealand where daily estimates of weather variables are modelled. These were also adjusted to localise them using equations reported by Norton (1985).

Method

Nine meteorological stations were established in association with forest experiments (Fig. 1). They all recorded rainfall, temperature, relative humidity, wind speed and global radiation on a half-hourly time step with sensors operating every few seconds. Seven of them employed ONSET equipment supplied as a package with the HOBO U30-NRC-SYS-B Weather Station (Onset Computer Corporation, USA). This system employs a HOBO U30 solar powered logger, a HOBO S-LIB-M003 Silicon Pyranometer Smart Sensor and standard ONSET temperature, rainfall and wind sensors. One station employed the same sensors but with a HOBO H21-002 battery-powered micrologger. The ninth station was a Delta-T Devices WS-GP1 compact weather station (Delta-T Devices Ltd., UK) with a solar-powered logger. All stations were mounted on tripods on flat terrain that was unsheltered by trees or local topography. The stations are listed in Table 1.

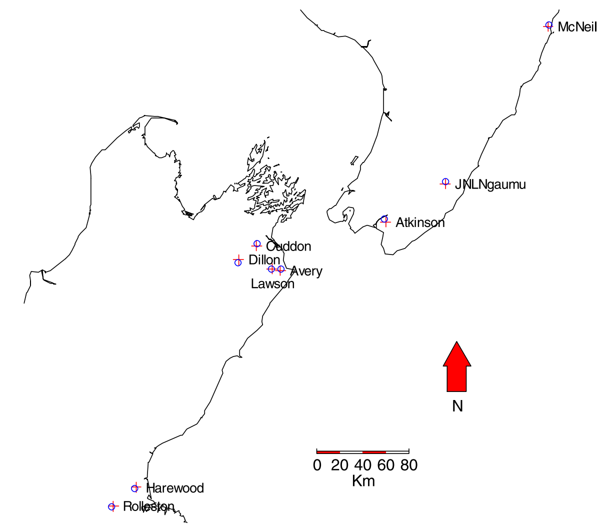

Fig. 1 Locations of independent meteorological stations (*crosses*) and the nearest NIWA Virtual Climate Station Network (VCSN) points (*circles*)

The National Institute of Water and Atmospheric Research operates meteorological stations throughout New Zealand, with a higher spatial frequency for some measurements than others. Spatial frequency is very high for rainfall, somewhat lower for temperature and low for radiation measurements. The closest NIWA stations to our experimental stations that covered the same time period were selected for each type of measurement, and their data was downloaded from the NIWA website. These data are provided as a free service to the community. Locations of the stations are shown in Table 2.

Staff at NIWA interpolate between meteorological stations to provide daily estimates of weather at 5 km by 5 km grid points throughout New Zealand (Tait et al. 2006), and this is known as the Virtual Climate Station Network (VCSN). The nearest grid points to the experimental stations were selected, and their data were kindly supplied to us by Dr Andrew Tait, Principal Scientist with the National Climate Centre. The locations of these grid points are shown in Fig. 1, and the distances between our stations and the points are shown in Table 1.

Data from all sources were summarised by year and month, with averages for all variables except rainfall, which was summed.

Mean daily maximum and minimum temperature estimates from NIWA were localised to our stations in two ways: (a) An adiabatic adjustment was made based on the difference between NIWA estimate point elevations and experimental station elevations (hereafter called "lapsed") and (b) equations predicting long-term monthly temperature means from elevation, latitude and distance from the sea (Norton 1985) (hereafter called "Norton-adjusted") were employed for both experimental station locations and the NIWA estimate point

Table 1 Experimental meteorological stations, their locations, locations of the virtual climate stations points closest to them and distance between them

Experimental station name	Symbol	Latitude	Longitude	Elevation (m)	Distance to coast (km)	Measurement period	VCSN latitude	VCSN longitude	VCSN elevation (m)	VCSN distance to coast (km)	Distance between experimental station and VCSN (m)
Avery		−41.7376	174.124	62	5	10/2014–6/2015	−41.725	174.125	71	6	1399
Lawson		−41.7226	174.0321	172	12	10/2014–6/2015	−41.725	174.025	136	13	648
Dillon		−41.6503	173.677	281	40	10/2014–6/2015	−41.675	173.675	427	38	2752
Cuddon		−41.539	173.8693	53	21	10/2014–6/2015	−41.525	173.875	28	19	1625
Atkinson		−41.3496	175.2407	60	5	2/2015–7/2015	−41.325	175.225	10	4	3032
JNL Ngaumu		−41.046	175.8764	241	14	2/2015–7/2015	−41.025	175.875	218	16	2344
McNeil		−39.7892	176.9706	282	2	2/2015–7/2015	−39.775	176.975	146	3	1623
Rolleston		−43.6182	172.3461	46	6	12/2008–8/2015	−43.625	172.325	52	6	1859
Harewood		−43.4668	172.5887	19	7	10/2013–9/2014	−43.475	172.575	22	8	1433

Table 2 Details of NIWA stations used for comparison with experimental station estimates of temperature, rainfall and radiation

Experimental station	NIWA Temp station number	Distance to NIWA station (km)	NIWA rainfall station number	Distance to NIWA rainfall station (km)	NIWA radiation station number	Distance to NIWA radiation station (km)
Lawson	4420	9.4	4420	9.4	12,430	25.5
Avery	4420	1.5	4420	1.5	12,430	29.7
Dillon	36,106	17.3	4319	14.3	36,106	17.3
Cuddon	4326	1.8	4326	1.8	4326	1.8
Atkinson	21,938	16.5	2665	3	21,938	16.5
JNL Nguamu	31,857	15.4	2613	14.2	37,662	17.3
McNeil	3017	19.2	3017	19.2	2980	37.7
Rolleston	17,603	10	4880	3	17,603	10
Harewood	4843	5.1	4843	5.1	4843	5.1

locations and the difference was added to the NIWA station estimates.

The NIWA estimates were compared with meteorological data recorded at the experimental stations in three ways:

1. Tables of correlations were prepared between both raw and adjusted NIWA estimates and actual recorded estimates of monthly weather statistics.
2. Graphs of observed versus estimated meteorological statistics were prepared with points coloured and labelled by station.
3. Graphs of residuals versus predicted values, differences in elevation and distances between our stations and NIWA estimate points were prepared.

Results

Temperature

Correlations between observed temperatures, VCSN estimates and nearest NIWA station estimates are shown in Table 3. Correlations tended to be high, and most frequently, the best transformations to local conditions were achieved by using Norton's (1985) equations, although a simple lapse calculation was slightly but not significantly better for maximum temperature from VCSN points. Correlations were higher with VCSN estimates than with nearest station estimates. Raw minimum temperature was slightly more highly correlated with observed temperature; however, Norton's equations may become useful for minimum temperature when stations and observed points differ greatly in distance from the sea.

Table 3 Correlations (expressed as *R* values) between observed mean daily maximum and minimum temperatures averaged by month, and estimates from either VCSN points or nearest NIWA meteorological stations, including some alternative localisations

Type	Maximum temperature	Minimum temperature
Raw VCSN	0.97	0.98
Lapsed VCSN	0.98	0.97
Norton VCSN	0.98	0.97
Raw NIWA station	0.96	0.91
Lapsed NIWA station	0.97	0.90
Norton NIWA station	0.97	0.91

Plots of observed temperature versus raw temperature and the best adjusted temperature are shown in Figs. 2 and 3, while residuals for the best estimates of observed temperatures are shown in Fig. 4. Even with adjustments, there is clear evidence of bias with station, but generally, the bias is not severe enough to affect the usefulness of the data.

Plots (not shown) of residuals versus (a) distances between estimate points and stations and (b) differences in elevation between estimate points and station points were created. Residuals of raw maximum VCSN and nearest NIWA station estimates were correlated with elevation difference, but adjusted estimates were less clearly correlated with elevation difference. Residuals of raw VCSN estimates tended to have a higher variance with distance, but not those of adjusted estimates nor did NIWA estimates vary with distance.

Radiation

Correlation between observed radiation and VCSN average monthly radiation was $R = 0.9914$, while that with radiation from the nearest NIWA meteorological station was $R = 0.9928$ (Fig. 5).

Residuals increased with distance between our stations and estimate points. Note also that despite having a higher correlation with observed values, the nearest NIWA station estimates were biased overall, with observed values generally larger than NIWA station values. Bias did not appear to be related to any particular feature, such as distance from, station or differences between NIWA station elevation and elevation of sample point.

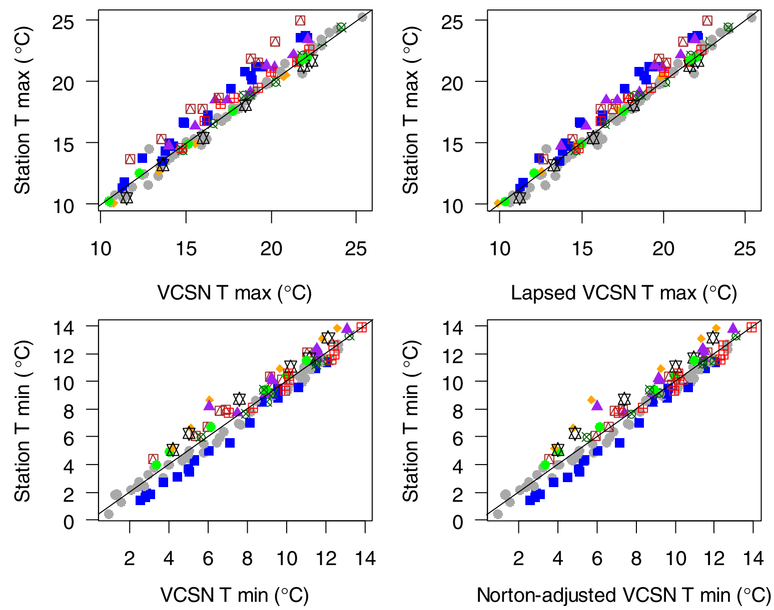

Fig. 2 Observed monthly average daily maximum temperature versus raw VCSN (*top left*) and lapsed VCSN (*top right*) estimates. Observed monthly average daily minimum temperature versus raw VCSN (*bottom left*) and Norton-adjusted VCSN (*bottom right*) estimates. Symbols show different observed meteorological stations

Rainfall

Correlations between observed rainfall and estimated rainfall were $R = 0.916$ and $R = 0.801$ for VCSN points and nearest NIWA rainfall station, respectively (Fig. 6), and the residuals were highly heteroscedastic. There was also a small tendency for residuals to increase with distance between our stations and VCSN points, but distance to NIWA rainfall stations appeared to matter little.

Vapour pressure deficit

The correlation between average monthly vapour pressure at our stations and VPD estimated at VCSN points was 0.83 (Fig. 7), with a tendency towards higher variance and

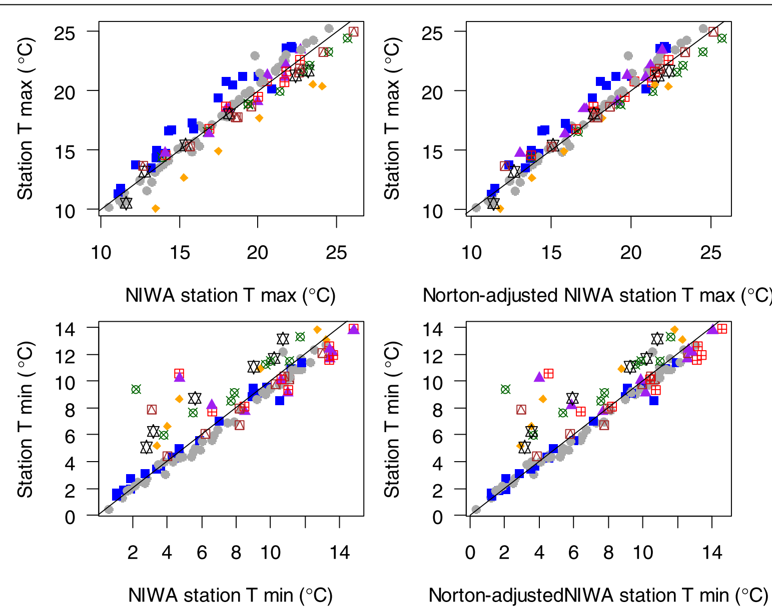

Fig. 3 Observed monthly average daily maximum temperature versus raw NIWA (*top left*) and Norton-adjusted NIWA (*top right*) nearest station estimates. Observed monthly average daily minimum temperature versus raw NIWA (*bottom left*) and Norton-adjusted NIWA (*bottom right*) nearest station estimates. Symbols show different observed meteorological stations

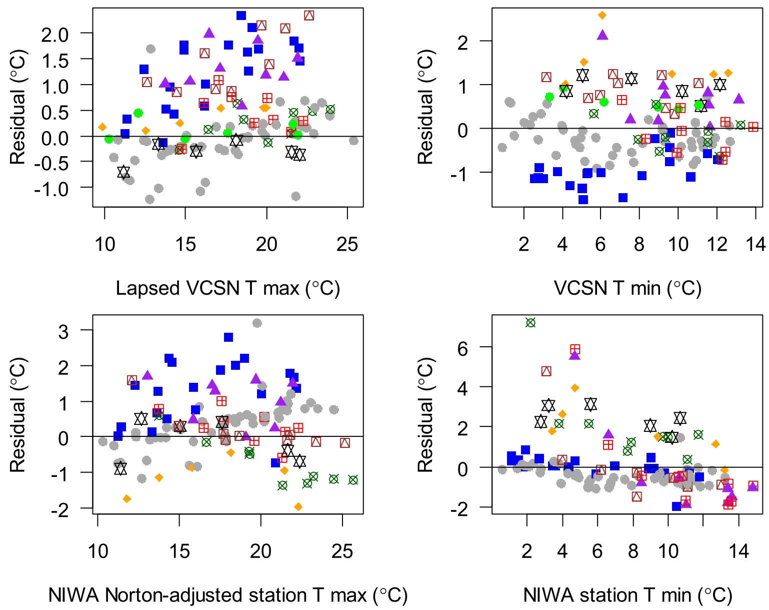

Fig. 4 Residual plots for **a** lapsed VCSN estimates of maximum temperature (*top left*), **b** raw VCSN estimates of minimum temperature (*top right*), **c** Norton-adjusted nearest NIWA station estimates of maximum temperature (*bottom left*) and **d** the nearest NIWA station estimates of minimum temperature (*bottom right*). Symbols show different observed meteorological stations

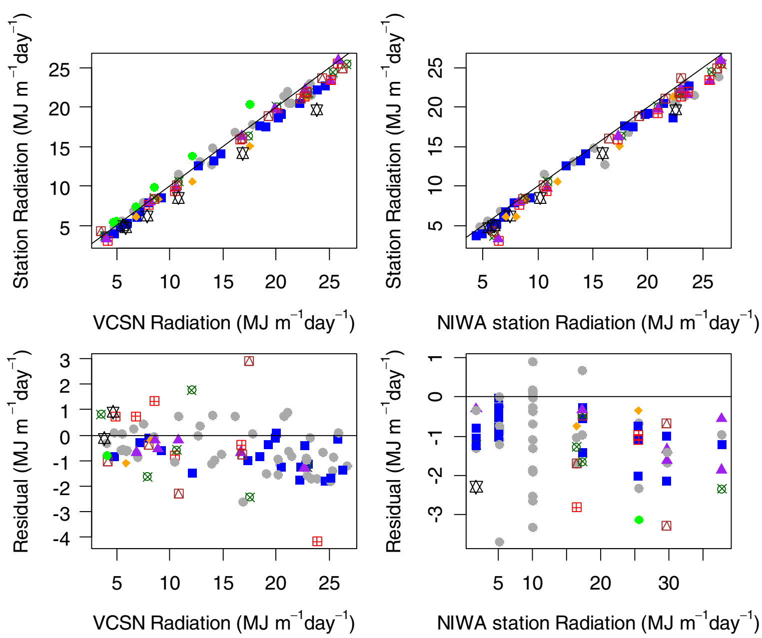

Fig. 5 Monthly average observed radiation versus VCSN estimates of radiation (*top left*), monthly average observed radiation versus nearest NIWA station radiation (*top right*), residuals of VCSN radiation estimates versus predicted value (*bottom left*) and residuals of nearest NIWA meteorological station estimates of radiation versus predicted value (*bottom right*). Symbols show different observed meteorological stations

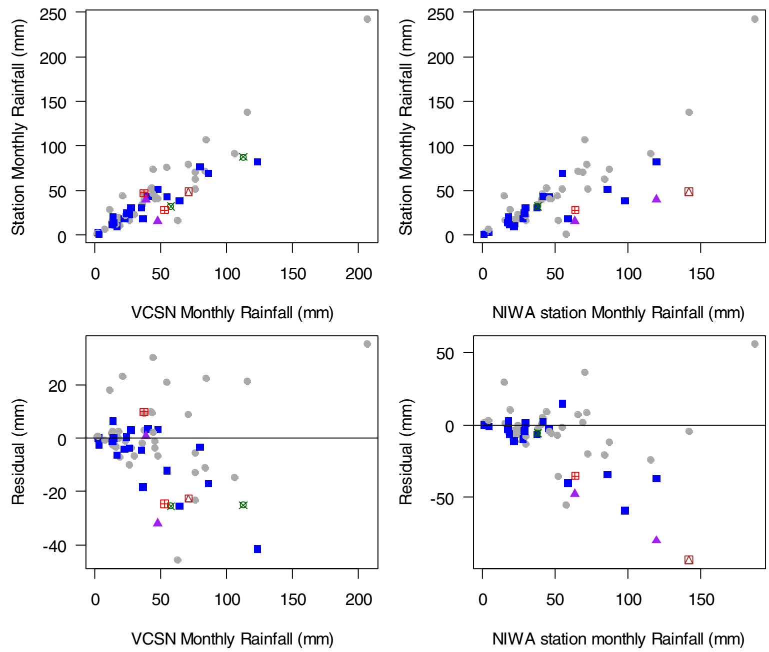

Fig. 6 Observed average monthly rainfall versus VCSN estimates (*top left*), observed average monthly rainfall versus nearest NIWA station estimates (*top right*), residuals of VCSN rainfall estimates versus predicted values (*bottom left*) and residuals of nearest NIWA rainfall station estimates versus predicted values (*bottom right*). Symbols show different observed meteorological stations

bias with decreasing relative humidity. There were no clear patterns of residuals with distance to VCNS point nor with elevation difference.

Discussion and conclusions

Clearly, the VCSN offers advantages over the nearest NIWA station estimates of variables that we require for eco-physiological modelling of forest growth for all variables examined in this study. Errors of most variables were relatively small, and estimates would be tolerable for our modelling efforts, although they will add to errors of estimates of eco-physiological models. Simple imprecision is likely to be less influential than consistent bias. As an illustration, a hybrid growth and yield model (Mason et al. 2011) was employed to estimate potential impacts of climate change by adding ~1 °C to both minimum and maximum temperatures (Fig. 8). When compared to NIWA VCSN estimates, some of our independent stations recorded biases of this magnitude (Fig. 4). The form of the model will matter, however, and yield models such as 3-PG (Landsberg and Waring 1997) would be more critically influenced by such input bias than growth and yield hybrid models employing difference equations, because difference equation models would take account of bias prior to starting points of simulations and adjust by adopting lower growth trajectories.

Rainfall was the most poorly estimated variable, and in some cases, the error may become very important in

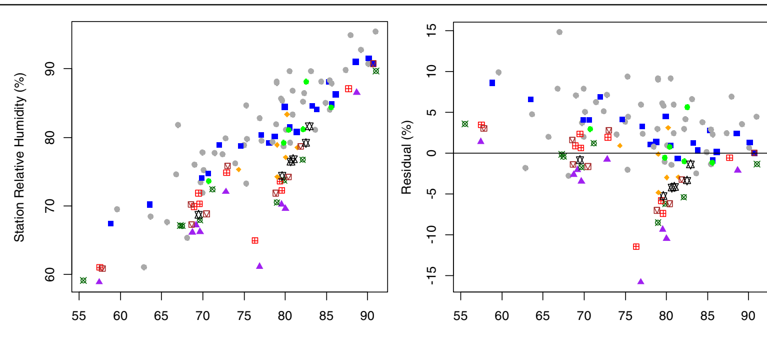

Fig. 7 Observed monthly average relative humidity versus VCSN estimates (*right*) and residuals versus predicted values (*left*). Symbols show different observed meteorological stations

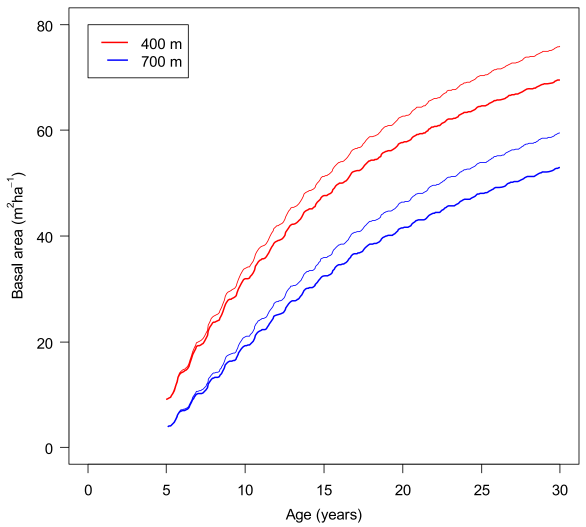

Fig. 8 An illustration of impacts of a ~1° centigrade bias in temperature on basal area per hectare projections using a hybrid growth and yield model in the Central North Island of New Zealand. The simulation was originally produced to illustrate potential impacts of climate change, adding 1 °C to summer and autumn temperatures, 0.9 °C to winter temperatures and 0.8 °C to spring temperatures (*thin lines*) compared to baseline projections (*thick lines*) at two different elevations

models, particularly in dry areas where water supply is the dominant factor influencing growth. NIWA has far more rainfall stations than stations that measure other variables, and clearly, NIWA's focus on rainfall measurements is justified as rainfall appears to be far more local than other variables.

We have concerns regarding the overall bias of NIWA station estimates of radiation because a consistent bias can accumulate errors. However, differences may reflect the particular locations and low level of replication of the experimental stations and corresponding NIWA radiation stations. Future studies with more stations may be able to identify better ways to localise estimates from VCSN points, thereby reducing bias.

There was a tendency for both VCSN and NIWA station estimates to be biased with respect to individual stations, and as expected, this bias was often related to distance between our stations and the estimate points. Adjustments of temperature using simple lapse adjustments for elevation differences or Norton adjustments for elevation, distance from the sea and latitude often reduced temperature estimate bias, particularly for maximum temperatures. Minimum temperatures are quite well estimated from VCSN points, and local adjustment offered little, if any, improvement in estimates.

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Authors' contributions
EM designed the study, helped with the setup and service meteorological stations, assembled the data, did the analysis and wrote the report. SS helped with the data collection. JM helped with the GIS aspects of the study and with the editorial comments on the report. All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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